Clinical evaluation of liquid crystal skin thermometers

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SUMMARY

We have examined two types of liquid crystal thermometers (LCT) designed for clinical use: one designed to measure skin surface temperature (LCTS) and the other had its calibration shifted by 1.9 °C to read a “core” temperature (LCTC). In laboratory tests with LCT on a glass beaker, there were highly significant correlations between temperatures measured by thermocouples, LCTS (r = 0.99) and LCTC (r = 0.99). In five patients undergoing cooling and warming during cardiopulmonary bypass with an LCT on their forehead, next to a thermocouple, the smallest correlation coefficient was 0.92. In 7.3% of observations in patients, the LCT scale was blurred, but readable. The graph relating LCT temperature and forehead thermocouple temperature showed hysteresis between the cooling and warming phases. An additional laboratory experiment suggested that LCT might be affected by draughts; they should therefore be protected from draught in use. (Br. J. Anaesth. 1994; 72: 246-249)

KEY WORDS

Equipment: thermometers. Temperature: measurement.

Temperature measurement using liquid crystals utilizes the fact that cholesteric liquid crystals alter their molecular structure in response to changes in temperature [1]. Liquid crystals can be deposited on a flexible plastic base to allow application to a curved surface. The “Crystaline” (Sharn Inc., Tampa, FL, U.S.A.) is a disposable liquid crystal thermometer (LCT) in which a gold liquid crystal line indicates the temperature on a Celsius scale at 0.5° intervals. This LCT is available in two forms: one measures skin temperature directly (range 26-38 °C); the other is calibrated to display a temperature 1.9 °C greater than skin temperature (range 29-41 °C). Both LCT have a hypo-allergenic adhesive backing which allows attachment to a smooth skin surface.

LCT may provide a safe and easy method of temperature monitoring, without concern over sterilization. Such monitoring may be useful for detecting early temperature increases in malignant hyperthermia [2].

The objective of this study was to evaluate these LCT in the laboratory and clinically in patients undergoing hypothermic cardiopulmonary bypass (CPB).

METHODS

For in vitro testing, the LCT were attached, one above the other, to the outside of a 2-litre glass beaker filled with water. An electronic thermometer (Mon-a-therm) (accurate to 0.1 °C against a mercury-in-glass thermometer) was used to measure temperatures and thermocouples were used to measure the temperature of the water, the ambient air temperature and the glass outer surface of the beaker on either side of the LCT. There was no perceptible draught over the LCT and during the experiment mean room temperature was 23.8 (SD 0.2) °C.

The water temperature was first increased by the addition of small volumes of hot water and then decreased by addition of cool water. The water was stirred thoroughly throughout and its level in the beaker was always above the position of the LCT on the beaker. The temperatures were recorded after each addition of water. To represent the surface temperature of the beaker, we calculated the mean temperature shown by the thermocouple positions, rather than by the LCT in one direction.

In addition, we studied five patients undergoing hypothermic CPB. Local Ethics Committee approval and informed patient consent were obtained. The LCT were applied, one above the other, to the centre of the forehead below the hairline. A Mon-a-therm electronic thermometer and thermocouples were used to measure forehead, nasopharyngeal and toe skin temperatures. Care was taken to avoid veins when siting LCT.

Two patients were cooled to 25 °C and one each to 28 °C, 29 °C and 32 °C (as measured from the nasopharyngeal temperature probe). Recordings were taken at 2-min intervals during the cooling and rewarming phases and at 15-min intervals at other times during the operations. The theatre temperature range was 23.9–26.2 °C during the experiments.

Records were available of temperatures throughout the anaesthetic, but we selected a continuous series of measurements to include the main hypothermic time and up to 5 min before and after, in order to analyse data over a range of temperatures. When the LCT gold indicator line lay between two calibration marks, we recorded the mean temperature calculated from the adjacent calibration marks.

Data were analysed using the Minitab version 7,
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using the linear regression and Mann-Whitney modules. \( P < 0.05 \) was considered significant.

RESULTS

Three hundred and twenty-seven measurements were analysed (in \( \text{vitro} \) studies and selected CPB results). In the \( \text{in vitro} \) studies the LCT display was always clear, but in 17 patients during CPB (7.3\%) the gold indicator line on the LCT was angled with respect to the scale and less clear, but nevertheless readable; these data have been included in the analysis.

The results for the beaker experiment are shown in figure 1, and summarized in table I. In figure 1 the temperatures measured by both LCT show a departure from the line of identity: vertical displacement and differences in slope. Table I demonstrates the relationships of the regression equations to that of the best fit straight line. For a perfect fit to the line of identity, the intercept values should all be 0 and the coefficients 1.0 for studies of skin-calibrated LCT, but the intercept should be 1.9 °C for the core-corrected LCT. The \( \text{SD} \) values indicate the reliability of the intercepts and coefficients.

We were surprised at the variability in the CPB results and replotted all the data, distinguishing between the points when temperature was decreasing and those when temperature was increasing. Figure 2 shows the resulting typical pattern of points—a type of hysteresis loop. The skin thermocouple and LCT temperatures followed each other during cooling, but as the body was warmed, the LCT readings moved ahead by as much as 1 °C. As the temperature increased, the loop closed and the relationship between the thermometers improved. This hysteresis occurred to some extent in all patients.

Because the points in figure 2 are spaced fairly evenly either side of the best fit line, the hysteresis itself does not make much difference to the final value for the slope or intercept. However, had the regression analysis been performed on a subset of the points (e.g. just during cooling), the results would be different. The implication is that overall correlations may be significant, but a single reading during one phase may be less reliable.

One possibility which might explain these results was that draughts cooled the uncovered LCT, but not the thermocouples, which were covered with an integral foam material. This prompted a further laboratory experiment in which LCT were covered in different ways. We compared readings from three LCT placed on a resting volunteer's forearm (avoiding veins and hair). These experiments were
conducted in a room in which the temperature was maintained constant by the theatre heating system. Ten minutes was allowed for equilibration before one LCT was covered with a plastic cover (medicine "tot") and another with a soft gauze swab and a clear plastic cover. An electric fan, 2 m distant, then directed a draught over the forearm for 10 min. After 2 min exercise, it was exercised by squeezing a rubber bulb for 2 min (table II). Initially, all three LCT displayed temperatures within 1.0 °C of each other; thereafter, the LCT covered with a swab changed least, whereas the open LCT indicated a 3.25 °C decrease in temperature in response to the artificial draught. After exercise, all three LCT indicated temperatures within 0.25 °C of each other.

**DISCUSSION**

The in vitro experiments suggest that, under the highly controlled conditions of the laboratory, LCT temperature displays follow those of a well established commercial thermocouple system. The high thermal conductivity of water and glass, compared with that of skin, ensures that the whole LCT is heated rapidly and evenly.

The accuracy of the LCT on patients is more difficult to evaluate because of the phenomenon of hysteresis, which may be influenced by several factors. The small thermal capacity of the LCT allows it to respond rapidly to changes in skin surface temperature, but it probably responds also to local draughts. A thermistor or thermocouple thermometer may have a greater thermal capacity than the LCT, some of it from the metal in the wires and the surrounding plastic, and respond more slowly to a sudden temperature change. In addition, our thermocouples had a thin foam covering. It may be that, when temperature changes rapidly, the thermocouple needs time to respond.

LCT are potentially useful in the detection of hyperthermia [2] and as trend indicators of core temperature during surgery [3–5]. Others have shown them to be inaccurate in detecting fever in children [6, 7] and poor at identifying core temperature trends both during surgery [8] and in the first 1 h after operation [9]. The LCT used here have the advantage of a continuous graded scale, with a constant colour being used for measurement.

**REFERENCES**


**TABLE II. Sequence of temperatures displayed by the three LCT. Where the gold indicator line lay between two values, the mean of the two was recorded; the second decimal indicates this situation**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Uncovered</th>
<th>Covered</th>
<th>Covered + swab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equilibration</td>
<td>35.25</td>
<td>34.25</td>
<td>34.75</td>
</tr>
<tr>
<td>10 min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan</td>
<td>32.25</td>
<td>34.0</td>
<td>34.75</td>
</tr>
<tr>
<td>5 min</td>
<td>32.0</td>
<td>34.0</td>
<td>34.75</td>
</tr>
<tr>
<td>10 min</td>
<td>32.25</td>
<td>33.75</td>
<td>34.75</td>
</tr>
<tr>
<td>No fan</td>
<td>33.75</td>
<td>33.75</td>
<td></td>
</tr>
<tr>
<td>5 min later</td>
<td>33.75</td>
<td>33.75</td>
<td></td>
</tr>
<tr>
<td>10 min later</td>
<td>33.75</td>
<td>33.75</td>
<td></td>
</tr>
<tr>
<td>Exercise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After 2 min exercise</td>
<td>34.75</td>
<td>34.75</td>
<td>34.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>35.0</td>
</tr>
</tbody>
</table>

We tested two forms of LCT from the same manufacturer: the skin LCT, and the core LCT which is adjusted to display 1.9 °C greater than skin temperature. Allen, Horrow and Rosenberg [4] studied core-adjusted LCT, similar to those we evaluated, in patients during the rewarming phase of cardiopulmonary bypass and demonstrated that the LCT temperature changed in parallel with the oesophageal temperature when plotted against time; the correlation coefficient of oesophageal temperature against LCT temperature was 0.67.

Because there are different concepts of what constitutes "core" under CPB, it is difficult to evaluate the core-correlated LCT. It is not clear, for example, how representative oesophageal temperature would be during CPB cooling (although this would not apply to the study by Allen, Horrow and Rosenberg [4], when cold fluid is applied to the heart and mediastinum [5]. There is also a wide variation in temperature along the oesophagus [10]. We believe that our nasopharyngeal temperatures may represent core temperature during the cooling phase of CPB more accurately and therefore provide a more representative comparison with the core-adjusted LCT. In general, however, we would not be confident in the ability of an LCT to monitor core temperatures during CPB, and the manufacturers do not suggest this use.

The skin LCT is potentially useful as a cheap, safe, non-invasive temperature trend indicator [2–5], with applications beyond simple temperature trend estimation. For example, increases in skin temperature occur with sympathetic nerve block and skin LCT may be used to indicate successful block [11]. It could be used also during transfer of patients and in situations in which electronic equipment might be inconvenient.

When beginning to adopt the use of LCT, we suggest that it would be wise to use standard thermocouple methods in parallel before changing exclusively to LCT. Furthermore, it would be wise to standardize air movement conditions over the LCT; probably the easiest method would be to cover the LCT with a clear plastic dome.
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